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Combined forest and soil management after a catastrophic event

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Abstract: At the end of October 2018, a storm of unprecedented strength severely damaged the forests of the eastern sector of the Italian Alps. The affected forest area covers 42,500 ha. The president of one of the damaged regions asked for help from the University of Padua. After eight months of discussion, the authors of this article wrote a consensus text. The sometimes asper debate brought to light some crucial aspects: 1) even experienced specialists may have various opinions based on scientific knowledge that lead to conflicting proposals for action. For some of them there is evidence that to restore a destroyed natural environment it is more judicious to do nothing; 2) the soil corresponds to a living structure and every ecosystem's management should be based on it; 3) faced with a catastrophe, people and politicians find themselves unarmed, also because they rarely have the scientific background to understand natural processes. Yet politicians are the only persons who make the key decisions that drive the economy in play and therefore determine the near future of our planet. This article is an attempt to respond directly to a governor with a degree in animal production science, who formally and prudently asked a university department called "Land, Environment, Agriculture and Forestry" for help before taking decisions; 4) the authors also propose an artistic

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interpretation of facts (uncontrolled storm) and conclusions (listen to the soil). Briefly, the authors identify the soil as an indispensable source for the renewal of the destroyed forest, give indications on how to prepare a map of the soils of the damaged region, and suggest to anchor on this soil map a series of silvicultural and soil management actions that will promote the soil conservation and the faster recovery of the natural dynamic stability and resilience.

Key words: Vaia storm; Wind damages; Soil organic carbon; Soil functioning; Humus form; Climate change

1 Background Introduction

1.1 Science and politics

Scientists have fewer and fewer choices other than engaging scientific knowledge in societal challenges. Yet, is it compatible with “doing science”? This question is worth asking since the future is not precisely fated, and ecological predictions may look like charlatanism. Strengths and weaknesses of ecology hold precisely in the unpredictable dimension of nature. The stochastic aspect brings considerable richness, allowing mechanisms such as interchangeability, founder effects, resilience, etc. System indeterminism is at the origin of ecologist discomfort when meeting requests for recipes. The duty of science holds probably more toward educating the glance than to manipulating nature. If society wishes more life, it should agree to lose some control over it to let every organism filling empty spaces and sharing a variety of ecological niches. In turn, every organism will be (or will construct) a habitat for adding a multitude of other species.

Consequently, the “letting go” philosophy or the will to let nature going by itself is at the core of the educational duty for scientists. Scientists must set up a back control of the way by which spontaneous dynamics serve humanity to check if this “letting go” philosophy brings some fruits, i.e., if the ecosystem goes in the direction of niche sharing and differentiation, that is a promise of biological richness. In this frame, scientists may play an active role in society, explaining the differences between natural wilderness and natural gardening. Both systems may hold a similar level of species diversity, but the former is self-organized while the second needs social skills to stabilize the ecological niche of each component. And the second alternative has an operational cost.

Society and Nature must evolve together. Humans are an outcome of Nature, humans are Nature. Nature exists and lives even without humans. The dynamics of living systems occurs by jumps. Nature essays "prototypes". If they don't work, Nature tries other unlimited in number designs. We need to deconstruct our human-sided view of Nature because the "correct way" stays in the future, and it does not exist a priori.

Humans struggle to distinguish between safe and dangerous progress. The "genetically modified organisms" are an example of ambiguous scientific attitudes: are these organisms the fruit of useful knowledge (a sort of intensified natural evolution) or models of unsafe progress? Back to the Vaia event, does the export of matter from a forest ecosystem influence its consistency in the future? Is it adequate to take away no more than the annual increment? Can we take away something from the wood without giving something in exchange for it? We can change the species composition of forests when economically advantageous. Is this a right or wrong move? When does a forest correspond to a group of living organisms? When does it, instead, correspond to a system of living organisms, with its functioning? Are we able to count the living organisms that make up a forest? Is it essential for humans to take care of this aspect of the story?

The authors of this article want to try a new formula for scientific articles. They propose to list the engaging opinions of a group of scientists and to address them to politicians for putting the views into practice. After presenting official data on the catastrophe, we pondered several publications that suggest some recommendations. The main issues are listed in the Conclusions as a letter addressed to one of the rare politicians who asked for scientific support before making operational decisions.

1.2 Soil As Digestive System (SADS)

SADS is a multinational group (the 23 authors of this article and four anonymous ecologists), composed of minds of diverse and co-evolving scientific opinions. The group took birth after a major storm over the North Veneto region (Italy) that came to the overall destruction of trees.

We know that forests generate from living soil. A forest ecosystem is composed of lasting organisms that use the soil as a secondary source of nutrients, the primary source being photosynthesis. The soil corresponds to a mandatory recycling center necessary for forest survival, in harmony with a local and relatively fixed climate and a geological substrate, in a specific morphology. Soil organisms digest dead organisms or parts of them, allowing reinvesting the products of past biological activities in living structures through the photosynthetic process. As for egg and hen, was soil born before photosynthesis or vice versa? The process of photosynthesis took probably place in the soil, at the origin, in bacteria evolving in algae, but in contrast with the digestive processes, the chloroplast activities are poorly diversified. Regardless of plant species, the photosynthetic function is taken in charge entirely unchanged. The digestive system is, in contrast, highly diversified and unequally distributed among the soil organisms. Fortuitously, it lies beneath the surface and remains quite invisible, and could be the Achille's heel of every ecosystem.

Speciation is a natural mechanism that drives living beings to fill the gaps between occupied ecological niches. Nowadays, world ecosystems have to cope with mundialization that brings new flows and new channels. Increasing mobility brings upheaval in both ecology and society. Species and populations carried away from any places around the world bring disruption of local equilibria. Population dynamics, in an environment with limited resources, are known for a long time (Volterra 1926; Kingsland 2015). A new incoming population increases slowly first, then rapidly and finally reaches an overall equilibrium, oscillating around a relatively stable value of environmental resources. Invasive species may be considered as monopolistic (a factor depleting biodiversity) or on the contrary, as a means to increase local biodiversity. The exportation of a universal model of sociological development upset the equilibrium of a millennium share of resources between humans and Nature. The belief and the system value that support the search for new stability cannot overlook economic constraints and the fact that richness unequally distributes.

On the one hand, an ecological system is ultimately a biological solution to dissipate solar energy (Zanella 2018). On the other hand, a sociological system is a solution to dissipate richness. Putting the analogy to the end, we know that an ecological system also has a hidden face that is soil as a digestive system (SADS), and we may wonder what a SADS could be for society. SADS is the regulatory focus of every ecosystem. From an organizational point of view, the counterpart of SADS to the society could be the dissipative mechanism that corresponds to the process of economic goods consumption. Thus, the instruments of a social SADS regulation could consist of taxes and allow public services to control the consumer society. Unfortunately, this captivating representation may work only in a virtual and with unlimited resources world. As we live in a real and limited resources world, we need to reconcile with Nature. Humans should limit their needs. Living and dead Nature should remain in a long-term balance. Social and natural SADS need to meet themselves and co-evolve.

1.3 Data

The Vaia event was quickly and well introduced (Motta et al. 2018). On October 27-29, 2018, intense sirocco currents, boosted by their passage over the Mediterranean Sea (during a summer season much warmer than average), struck north-eastern Italy. Wind currents channeled along the slopes of many Alpine valleys reaching speeds of over 150 km/h (Figure 1).

The Directorate General Forests of the Ministry of Agriculture, Food and Forestry and Tourism established a technical table with the Regions and Autonomous Provinces of Northern Italy affected by the storm. A few weeks after the disastrous event, the committee released the first quantitative analyses of the extensive damages to the national forest heritage. The analyzes base on local authorities' damage estimates, through field surveys and interpretation of aerial and satellite images, and with the support of numerous universities and forest research institutes.

The forests of 473 municipalities were damaged. The affected forest area covered 42,500 ha, where an almost total knockdown of trees was observed, to which a similar surface having suffered partial damages should be added. Most affected areas were located in the Autonomous Province of Trento with over 18,000 ha of felled forests and Veneto with over 12,000, followed by Alto Adige, Lombardy and Friuli. Slight damages were noticed in Piedmont and Valle d'Aosta.

Figure 1 Left: Centre of Studies for the Alpine Environment (Belluno, Dolomites, Italy) on October 30, 2018, on the day after the event. Notice fallen trees on the roof of the building and part of the damages done in its vicinity. Right: Same position two months later (January 4, 2019), with the first restoration works (Photographs: Roberto Menardi).

The volume of timber on the ground in the 42,500 most damaged areas reaches about 8,300,000 cubic meters. Based on these estimates, the Vaia storm is the most destructive event ever recorded in Italian forests.

This kind of storm in Central Europe has become now quite common and is the cause of about 50% of forest damage in the last 100 years. The average rate of major or critical storms which hit Central Europe is two a year (the most famous cases being Vivian in 1990 and Lothar in 1999 with damages equal to about 200 million cubic meters).

1.4 Criticalities

Downstream damaged forests, the function of protection of settlements, and human activities will be severely affected by falling rocks, avalanches, landslides for a period ranging from a few to tens of years. This situation will last until the post-storm renewal has been established.

Risks of disease to surviving forest stands, primarily dominated by northern spruce (*Picea abies* (L.) Karst), are caused by the proliferation of Scolytidae's insects. They deposit eggs in fallen wood from which the populations can invade the surrounding forest stands, especially in the presence of a climatically favorable spring.

The danger of spreading fires is increased by the high amount of deadwood mixed with grass and shrubs. This can give rise to highly flammable fuel and generates high flame front intensities.

Significant economic damages to the chain of wood products are due to the low price at which wood is sold on the ground, an amount which still decreases rapidly over time because of the alteration of technologic quality. This sharply reduces the opportunity of public and private owners to benefit from the economic value of these highly productive forests. At the same time, harvesting all fallen timber will require 2-3 years, enough to bring down the price of wood in a period of excess supply, with adverse effects on the national forest sector of activity.

Ordinary forest management is abandoned in non-damaged stands, as foreseen by planning tools, following commitment for emergency management of harvested timber.

About the safety of the personnel employed in crashed forest site areas, where the felling and extraction of wood are complicated and dangerous due to strong wood tensile forces, thus there is a high criticality. Some workers have already lost their lives on the worksites in progress. For these activities, the high professionalism of the operators is required.

We expect a significant modification in the structure and composition of habitats of Community interest (Natura 2000, a network of protected areas in Europe), with inevitable repercussions on behaviour, survival, and dispersal of animal and plant species.

1.5 Immediate reaction

From the beginning, the experts correlated the increase in temperature of the Mediterranean Sea with a higher quantity of energy and water vapor, which corresponded to the incredible virulence of the specific meteorological phenomena occurred on October 29, 2018. Was the Vaia storm a perverse fruit of such a climate change on which so much people discuss? The soil "fluidized" reducing the root seal. The strong wind (about 100-130 km/h) produced localized whirlwinds due to roughness and micro-orographic peculiarities, which, allied to canopy rocking, caused the observed damages (Cat

Berro et al. 2018; Barcikowska et al. 2018).

What percentage of vegetation would still be let in place if more responsible forest practices had favored a diversification of forest stands (Bormann and Likens 2012; Arts et al. 2013; Motta et al. 2018)? Besides, great neglect was given meanwhile to the margins of forest stands: compactness of the border vegetation between a meadow and the forest is almost always lacking (Figure 2, Left compared Right pictures).

You can enter immediately in the heart of the forest, too often thinned out by intensive use, more markedly in private forests. In most low and medium mountain forests, in search of higher economic rent, spruce has always been favored, "cultivated" in even-aged pure populations (Indermühle et al. 2005; Gonzalez et al. 2010; Kauppi et al. 2018). This species has a superficial root system (Figure 3 Right), and, in the event of a wind blow, its stands suffer from a domino effect (Merzari et al. 2018), as it also happened this time (Figure 3 Left).

In forest stands where trees were more diversified in age and species, devastating effects of the wind were more restricted, with a better resistance due to different morphology of the root system (white fir, larch, beech, and other deciduous trees). In damaged areas, only some larches (with little "sail effect" causing canopy rocking) and sometimes hardwoods remained standing. They survived the disaster for "intrinsic properties", not only because they bypassed by crashed vegetation (Figure 3 Left). Merzari et al. (2018) reported: "Reasonably if we had mixed woods with different species (like spruce, fir, beech, and other species) of different ages able to better use the vertical space of the foliage, and with younger and more elastic plants, all this would have been limited to some portion of the forest". A more diversified forest was promoted for years, even in books of the founder of the Centre for Studies on Alpine Environment (Figure 1) and President of the School of Forestry Science of the University of Padua (Susmel 1980; Giannini and Susmel 2006).

We hope that management errors will be recognized and, after having removed where and when possible fallen timber, management will follow the principles of close-to-nature forestry. We expect that foresters will concretely apply these principles according to the vocation of individual forest sites to spontaneously evolve in natural succession: from pioneer species of open spaces (for example larch) to the multi-layered uneven, multi-species high forest to which, where allowed by altitude, broadleaved trees like beech or maple conspicuously participate with adequate density (Susmel 1980).

Figure 2 Left: Forest without a mantel, easily subject to wind blows. Cadino Valley, Trento (photograph: Valter Giosele, July 8, 2019). Right: forest with shrubby mantel that resists strong winds. Boite valley, Belluno (Roberto Menardi, July 11, 2019). The two forests are located at nearby altitudes and slopes.

Figure 3 Left: In this population of spruce and larch destroyed by the Vaia storm, only some larches remained standing. The deeper, more solid root system and the lighter foliage probably made the difference (photograph: Roberto Menardi, November 9, 2018). Right: the root system of Picea abies does not allow isolated trees to withstand strong winds (photograph: Roberto Menardi, January 4, 2019).

The hydrogeological defense action of the forest and rainwater regulation can still be carried out, above all, on the steepest and most https://www.pefc.org)/inaccessible areas where it is more difficult and dangerous to collect timber. Compared to an entirely denuded ground, trunks fallen on the ground may protect it (BAFU 2008; Cislaghi et al. 2019). Infestations of xylophagous insects may undoubtedly happen in spring, but they can be opposed in turn by other competitors.

So, in any case, it is preferable, when possible, to prevent landslides. In general, we suggest avoiding the use of forestry machinery that can affect the ground and cause irreparable secondary damages, resulting in gulling erosion figures (Figure 4). Practical solutions to the management of forest stands to prevent soil erosion and landslides can be found in the results of recent research projects (Costantini et al. 2017).

Figure 4 The passage of mechanical machinery necessary for the removal of fallen trees causes important (irremediable?) injuries to the soil. Left: the spatial dimension of the damage can be vast. Right: ground disturbance can also be locally profound. Near Perarolo (Belluno province) (photographs: Augusto Zanella, May 4, 2019).

1.6 Ecological catastrophes and "butterfly effect"

Almost all wind-damaged areas were managed sustainably according to international standards of PEFC (Programme for the Endorsement of Forest Certification: https://www.pefc.org), a non-government organization that certifies the sustainable management of forests and forest products. Therefore, the cause of the lousy state of damaged forests is certainly not attributable to their abandonment. How is it possible that well-kept forests suffer such serious damage? An explanation could be that perpetual disturbance and disequilibrium could be a natural law (Motta 2018). However, without equilibrium a system does not stand up, and this might contradict a thesis of perpetual disequilibrium. It could be the balance covering of a system in "unstable equilibrium", i.e., a continually evolving complex ecosystem. A forest displays century-old cycles, inserted in geological periods of several millennia. A forest includes trees with several-century growth cycles, plants, and animals with 10-yr, annual, or monthly cycles, up to the cycles of micro-organisms that are of days to hours or even minutes. Every sub-system is moving in a changing equilibrium. However, thinking that a world without balance exists, means disregarding ecology. If a catastrophe may stir the pot, there should be a trend, a force that allows recovering a momentarily lost original equilibrium (as in the aging of every natural system, like the growth of a child). Of course, the reference point of such evolution is in the future and remains theoretical. Nevertheless, this "final theoretical forest" will be mobile but measurable after the forest has started to regrow. We are talking about a concept attributable to the chaos theory (Lorenz 1963; Mandelbrot 1983; Gleick and Hilborn 1988; Nottale and Schumacher 1998; Nottale 2003; Ponge 2005; Zanella 2018). Chaos theory does not say that things are out of balance, and that sooner or later they can / must fall into disrepair. On the contrary, it announces an unpredictable but balanced and continuous becoming. And this means studying the forest as a system in the making, with its own and still unknown laws. To do this we need a lot of patience, a lot of research, respect for the future and a lot of prudence. These aspects were addressed with foresight during a historical conference in Italy (Ciancio 2010, 2015). That left the Italian forest managers' society divided, faced with a poorly understood proposal called "systemic silviculture". Unfortunately, however, the consequences of the past forestry are before our eyes, landed. From (Ciancio 2009): "Science has value if it is capable of explaining and predicting. The dominant scientific culture is aimed at planning the future on the basis of data acquired with experiments and observations. Well, in biology and forestry, current knowledge does not allow us to be certain that the change in some conditions does not affect the results. The uncertainty derives from the fact that it operates in a changing environment. As it is easy to guess, this factual datum involves methodological problems, on which, instead of pausing to reflect, one often flies over with great ease".

It is now clear to everyone that we must change our attitude towards the woods. Radical changes need to be made in the scientific approach. The debate on forest management must be resumed on a new basis, otherwise we end up governing the past: what has been acquired is transcribed or repeated in environmental conditions and in socio-economic situations different from the current ones. And to pay the price, needless to say, will always be the forest.

We must be pervaded by the idea that science is made of data, like a forest of trees, but a mass of data is not science just as a set of trees is not a forest.

It is useful to refer to the term "catastrophe" as used in ecology, in the framework of the complexity epistemology.

Nature is a complex system whose components interact in multiple ways and follow local rules, meaning there is no reasonable higher instruction to define the various possible interactions (Prigogine et al. 1974; Nicolis and Auchmuty 1974; Zeeman 1976). René Thom in the 1960s firstly exposed a theory of catastrophes applied to different domains. For us, all this is relevant because we can formulate plans of actions, based on our various pieces of knowledge and experiences, but without having the presumption to provide solutions valid for everywhere. For this reason, we prefer to remain general in our approach and suggestions: i) use part of the accessible timbers, since there is an immediate economic and social interest, besides reducing the risks of fire and landslides, ii) leave all the rest on the ground to protect soil from water erosion. In Long term actions chapter (4.1.), we propose to harmonize this second solution according to the amount and kind of necromass left, the type of soil and humus profile, and other local factors.

1.7 Why is soil so important after a catastrophic event like Vaia?

Soil is a natural body which tends to self-organization (Costantini and Lorenzetti 2013); functionally, it corresponds to a vast digestive and accumulative system fed by organic and/or mineral compounds (Zanella et al. 2018d). The biological processes of demolition, selection, storage, reapplication of energy and building material from transformed mineral and organic matters occur in every living organism (belly, with the meaning of "internal and under control soil"). The evolution of life on Earth generated increasingly complex natural ecosystems, accomplished by breaking down mineral and organic structures and using the resulting elemental pieces and energy for assembling new organisms in new habitats and ecosystems (Gobat and Guenat 2019).

Pedodiversity is important because it is related and probably supports biodiversity (Costantini and L'Abate 2016). The natural self-organization process of the soil profile is highly variable depending on local conditions (Costantini et al. 2013). The response of the soil system to catastrophes depends on the degree and type of self-organization reached by the soil at the time of the catastrophe. The rule is that the more organized the soil, the more resilient it is, and this up to the moment of breakage (landslide, accelerated erosion, artificial excavation). After this break, it is no longer possible to return to the pre-existing state of equilibrium. On the other hand, in the case of young, simple, poorly evolved soils, resilience is less consistent (they change quickly), and also return more quickly to the previous state after the catastrophic event.

Earthworm communities are diverse in various types of European forests (Wandeler 2018); we do not think that the hypothesis that plants and earthworms could coevolve still stuns someone.

Trees seem to speak to each other as in a big family that occupies a whole forest-ecosystem. Also supportive for an audience of non-specialists, we mention two books of worldwide success in which the results of countless scientific works prove the existence of natural systems, not of species with individualistic strategy. To the point of questioning the possibility that species make ecosystems; it would seem that only ecosystems can arise, not single species, or only species as parts of functional sets (Wohlleben 2016, 2018). The means of communication of trees are molecular signals that fly in the air or travel in the soil. This "chemical language" allows trees to face adversity and dangerous parasites as well as to find resources for feeding themselves and their progeniture. Wohlleben's books are founded on scientific truth and may recall the concept of Gaia developed by Lovelock and Marginus (Lovelock and Margulis 1974).

There is a French book entitled "Jamais Seul. Ces microbes qui constituent les plantes, les animaux et les civilisations" (Never Alone. These microbes that build plants, animals and civilizations). Its charming black and white cover exposes in a glance the content of the book (Selosse 2017). Go and look at it here: https://www.actes-sud.fr/node/59704.

Soil is an after storm available seed bank. Forest managers have to expect a shortage of tree seeds in old even-aged forests; on the contrary, a rich bank of tree seeds may be found in the juvenile phases of more natural uneven-aged forests (Alessio Leck et al. 1989; Rees 1994; Thompson 2000). Seed bank densities are higher in nutrient-rich soils (Berger et al. 2004). Nitrate treatments do not promote germination of viable buried seeds (Berger et al. 2004). The spruce forest regeneration starts where light reaches the ground; however, the sunlight will above all favour the development of grass seeds, and it will be necessary to cover the soil (with branches of fallen trees) to favour the growth of trees (Thompson et al. 2003).

No matter how much biomass lies on the ground today, the soil-system will digest everything. Bark beetles can destroy the still living part of the forest system, especially if the standing forest has an anthropic origin and is not in equilibrium with the environment in which it developed. A healthy forest will not let the bark beetles dictate their law (Paoletti 1999; Seidl and Blennow 2012; Morris et al. 2018). If man intervenes as little as possible, the new forest will grow in harmony with the climate and environment of the region. By integrating the carbon of dead trees into new living organisms, the forest will even mitigate ongoing climate change, storing in the soil a part of the carbon that was in the fallen timber. The ramial chipped wood technique seems to be made for our case and deserves a large-scale attempt (Asselineau and Donenech 2013), why do not try at least in areas where rehabilitation requires human intervention?

Tree species identity, particularly N-fixing species, seems to have a stronger impact on soil C stocks than tree species diversity (Mayer et al. 2020). In forests with high populations of ungulate herbivores, reduction in herbivory levels can increase soil C stocks (Mayer et al. 2020). Specific composition of the tree population and humus forms are very correlated (Wandeler 2018). The reason lies in the quality of the bedding produced by trees, which is related to soil biodiversity (Chapter 4.1).

About important ectomycorrhizal and arbuscular mycorrhizae recent discoveries; selected phrases from (Popkin 2019): "Trees, from the mighty redwoods to slender dogwoods, would be nothing without their microbial sidekicks. Millions of species of fungi and bacteria swap nutrients between soil and the roots of trees, forming a vast, interconnected web of organisms throughout the woods. Now, for the first time, scientists have mapped this "wood wide web" on a global scale, using a database of more than 28,000 tree species living in more than 70 countries. Earth has about 3 trillion trees. Each tree is closely associated with certain types of microbes. For example, oak and pine tree roots are surrounded by ectomycorrhizal (EM) fungi that can build vast underground networks in their search for nutrients. Maple and cedar trees, by contrast, prefer arbuscular mycorrhizae (AM), which burrow directly into trees' root cells but form smaller soil webs. The researchers wrote a computer algorithm to search for correlations between the EM-, AM-, and nitrogen-fixer–associated trees and local environmental factors such as temperature, precipitation, soil chemistry, and topography. In cool temperate and boreal forests, where wood and organic matter decay slowly, network-building EM fungi rule. About four in five trees in North America, Europe, and Asia associate with these fungi. By contrast, in the warmer tropics where wood and organic matter decay quickly, AM fungi dominate. These fungi form smaller webs and do less inter-tree swapping, meaning the tropical wood wide web is likely more localized. About 90% of all tree species associate with AM fungi. The findings could, for example, help researchers build better computer models to predict how much carbon forests will squirrel away and how much they will spew into the atmosphere as the climate warms. As the planet warms, about 10% of EM-associated trees could be replaced by AM-associated trees. Microbes in forests dominated by AM fungi churn through carbon-containing organic matter faster, so they could liberate lots of heat-trapping carbon dioxide quickly, potentially accelerating a climate change process that is already happening at a frightening pace".

1.8 Soils affected by VAIA storm

With the aim of developing a strategy of interventions related to soil types, we simply superimposed the map of the areas destroyed by VAIA (Chirici et al. 2019) to that of the soils in the Veneto region (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto 2015). We then listed these soils on a table (Appendix 1), associating each of them with the most likely humus system. A quick and punctual search of sample sites has proven these realities but has not allowed to recognize the most precise mesh of the humus forms. It would have required a more accurate sampling that could possibly be carried out during the research proposed in chapter 4.2., To better define the degradation times related to each humus system.

The VAIA damaged area is characterized by Leptosols, Cambisols, Phaeozems, Luvisols and Podzosols with Mull, Moder, Amphi, Tangel and Mor humus systems.

We will use this knowledge to estimate the duration of biodegradation of wood material on different humus systems.

2 A Crucial Question: Why Not Let Nature Curing Its Wounds by Herself?

Below we summarize the answers of the authors of the present article. A complete version of their thinking is published in an open access draft of the article (Zanella et al. 2019). The answers have been specifically arranged in two opposite categories which correspond to the "for" and "against" of letting Nature heal itself. After reading them it will be necessary to choose an intervention strategy.

2.1 No, damaged forests need management

Consider other similar events as an example (Figure 5) and consequent results of given interventions.

1. Removing fallen trees as quickly as possible increases the possibilities of rational wood management and protects against pest degradation (Directorate-General of the State Forests 2017; Wesołowski and Zmihorski 2018).

2. Do not leave dead wood on the ground; a fast intervention that takes away the timbers will prevent bark beetle damage (Zastocki et al. 2018).

3. An accumulation of necromass on the ground leads to a thickening of the transition from organic to inorganic soil horizons and lowers the CH_4 uptake, reducing the ability of forest soil to lower GHG in the atmosphere (Lorenzetti et al. 2019).

4. Space (dimension of the damaged area) and time (forest cycle) should be considered as well as the origin of the species used in eventual plantations (Motta et al. 2002, 2006; Bottalico et al. 2016; Kulakowski et al. 2017; Motta 2018; Chirici et al. 2019).

5. Eventually, re-create multiplane and multi-age forests. Mixed forests have a more natural structure and more stable vegetation as a consequence. The blowdown areas need to be assessed or classified according to their specific site condition and situation in the landscape (a concerted effort should be started to retrieve old records of local natural forest vegetation). In a second time, differentiated site and landscape adequate reactions (soil potentiality in the context of sites and differentiated priorities) should be planned (Susmel 1980; Giannini and Susmel 2006).

6. Many years (from 57 to 106 years) are needed to achieve an advanced decay for fir and spruce logs, while leaves, needles and small branches will provide an important input of organic matter at the soil surface in the short time (Spears and Lajtha 2005; Přívětivý et al. 2016).

7. Lack of a forest cover will enhance nutrient losses because of lack of biological recycling of element (Jastrow et al. 2007; Smolander et al. 2008; Falsone et al. 2012; Strukelj et al. 2013; Xu and Chen 2016; Magnússon et al. 2016; Zhang et al. 2018).

Figure 5 View of the state forest of Cadino Valley, resumed the day after the storm of November 4, 1966, taken from Aprie (http://www.forestedemaniali.provincia.tn.it/forestedemaniali/cadino/pagina2.html)

8. If a long time passes before revegetation occurs, the new equilibrium between forest and soil will favor a poorly fertile system (Jobbágy and Jackson 2001; Balogh-Brunstad et al. 2008; Stanchi et al. 2012; Bonifacio et al. 2013).

9. Attention should be paid to the role of the storms in the natural dynamics of the forest, a consequence of this should be a departure from the acute elimination of windstorm effects in favour of partially leaving the forest to natural succession and regeneration processes (Directorate-General of the State Forests 2017; Wesołowski and Zmihorski 2018).

10. In cleared areas, leaving branch wood on the ground could be very useful to protect the soil ecosystem (Berhongaray and Ceulemans 2014; Machar et al. 2016; Baran et al. 2018; Barančíková et al. 2018).

11. Fallen trees should be removed (Valinger et al. 2014, 2019).

12. Soil nutrients increase in damaged areas due to reduction of biological demand (McNulty 2002).

13. The new forest should be adapted to incoming extreme events. Climate change is considered as one of the big threats for forestry (IPCC 2014; Keenan 2015; Andersson et al. 2018).

2.2 Yes, forest will recover by itself

1. Wait at least ten years before intervening, letting Nature try something by Herself first (Spurr 1956; Stokland et al. 2012).

2. Do not chip fallen wood (Strom 1985; Taylor and Carmichael 2003; Tang et al. 2004; Machrafi et al. 2006).

3. When regeneration becomes improbable on the ground, it is very often vigorous on the trunks of decaying trees (Attenborough 1995; Szewczyk and Szwagrzyk 1996; Zielonka and Piątek 2001; Zielonka and Piątek 2004; Motta et al. 2006; Zielonka 2006; Génot et al. 2011; Fukasawa 2012; Tsujino et al. 2013; Orman and Szewczyk 2015; Guo 2016; Wohlgemuth et al. 2017; Parisi et al. 2018; Taeroe et al. 2019)).

4. Animals have a substantial impact on plant regeneration: are large herbivores regulated by carnivores?

5. In the case of fragile forests, it would be better to cut batches of trees and abandon them on the site to increase the deadwood mass on the ground (Guo 2016; Diaci et al. 2017).

6. Identify areas with pre-existing forest tree seedlings within the perimeter affected by the storm (Fischer et al. 2002; Motta et al. 2006; Orman and Szewczyk 2015).

7. Identify patches of dense ground vegetation (of ericaceous type, Calamagrostis, etc.) which could shortly show an explosive kind of development and in this case avoid clearing the windthrow (Kuuluvainen 1994; Szewczyk and Szwagrzyk 1996; Zielonka 2006; Ilisson et al. 2007; Tsujino et al. 2013; Martiník et al. 2014).

8. Take a close look at mounds and pits of uprooted trees because they are environments where the bare mineral soil is a micro-site favorable to regeneration. It can be beneficial to bring maximum light to these mounds (Attembourg 1995; Szewczyk and Szwagrzyk 1996; Zielonka and Piatek 2001, 2004; Zielonka 2006; Motta et al. 2006; Génot et al. 2011; Fukasawa 2012; Tsujino et al. 2013; Orman and Szeczyk 2015; Guo 2016; Taeroe et al. 2019).

9. Protected areas could not to be subjected to any interventions (Jackson et al. 2009; Čerevková and Renčo 2009; Bischetti et al. 2009; Vodde et al. 2011; Bell et al. 2014; Cambi et al. 2015; Barančíková et al. 2018; Cislaghi et al. 2019).

10. In other managed state forests, it would be advisable to remove just a part of bigger logs (Siira-Pietikäinen et al. 2001; Faccoli and Bernardinelli 2014).

11. Coppices should be banned from the VAIA area (Gardiner et al. 2013; Clauser 2018).

The forest ecosystem is creative and adaptive. In Switzerland, we knew Lothar, a powerful storm at the end of December 1999. In the 288 ha Creux du Van forest (canton of Neuchâtel), despite the fear and protests of neighboring forest owners (due to a possible rapid reproduction and spread of bark beetles), it was decided to leave all the fallen trees in place on a surface of 102 ha and to build a forest sanctuary (disturbances are opportunities to restore natural processes). Twenty years later, the renewal of this area (Abieti-Fagetum) shows unpredictable vigor (Figure 6 Left).

In managed forests, the adopted scheme of actions after hurricane disasters consist in "clearing up" damaged trees and artificially regenerate post-mortem areas, which from the

Figure 6 Left: the young spruce trees thrive between the trunks of fallen and decaying trees. The trunk on the left touches the ground and is more decomposed than the one on the right, which is held up above the ground by its branches. Right: A vigorous silver fir with 20 cm annual growth. Behind it, a decomposing trunk covered with mosses. Notice that behind the fir branches, beech and lime are composing a mixed forest. Soil: from Rendzic Phaeozems - Entic Hapludolls to Haplic Cambisols - Inceptic Haprendolls; Humus systems: from Amphi to Mull, respectively. The decomposition process appears to be in line with the provisions in Figure 7, between the lines of Mull and Amphi-Moder systems.

point of view of natural forest ecosystems should be considered inappropriate (Seidl et al. 2017).

The population should be informed with the production of leaflets and updated on the situation in itinere (Sadri et al. 2017; Barančíková et al. 2018).

In most of these answers it appears clearly how the soil plays a predominant role in restoring the health and functionality of the destroyed forest. For this reason, we propose below to put it at the center of the recovery actions. The landed forest must be classified according to the soil and the interventions must be based on the answers that we expect from the soil.

3 Short Term Actions (1-5 years): Security, Vulnerability/Sensitivity Analysis and Maps

We know very well what needs to be done immediately after a catastrophe. Manuals have been published and there are examples to imitate. Here is one (Katzensteiner et al. 2016):

In short:

1) Experts on Alpine Natural Hazards/ Torrent- and Avalanche Control) can map critical zones for those disasters (there may be positive effects of residuals as they create surface roughness and prevent snow gliding, there may be negative effects by stems blocking streams, etc.) with priority ranking and, depending on the situation, advices on the degree of intervention.

2) Experts on area types (ownership, accessibility) can map forest type, structure and management, soil and humus types.

3) Bark beetle risk assessment (Baier et al. 2007), resumed here by the Risk Assessment Group of the Institute of Forest Entomology, Forest Pathology and Forest Protection, Department of Forest and Soil Sciences, BOKU - University of Natural Resources and Life Sciences, Vienna: http://ifff-server.boku.ac.at/wordpress/index.php/home/phenips-online/

4) Regeneration, the question of natural regeneration versus planting is an issue and will determine costs. How to make use of that potential?

5) Ungulate browsing will be a serious issue in the future. How to act on that?

I don't have time to come up with a careful DPSIR analysis by now, but I will continue to work along those lines.

6) Set up an Endnote-Web literature database.

7) Mapping: a) Critical zones and SECURITY, b) Accessibility (roads) and c) Regeneration and ungulate pressure.

4 Soil and Forest Rebirth

Before presenting a project of forest recovery, let's spend another two words on the soil and specify the reasons that guide the development of such a type of reforestation plan.

There are no tables with the duration of biodegradation of whole trees in the forest. Instead, the becoming of dead wood on the forest floor and the classification of the material in the evolving phases have been described and published by (Zanella et al. 2018c; Tatti et al. 2018). No estimates were made on the time needed for the biotransformation of wood because the factors that influence the speed of biodegradation are numerous and interdependent (Tatti et al. 2018): geological substrate, soil (particle size, pH, CEC...), climate, topography and contact surface between soil and deadwood, living organisms including microbial organisms, type of surrounding vegetation, tree/shrub species, initial decay stage of the woody material, quantity/volume, type, shape and size of the initial woody material. There are works that link the rate of decomposition to the lignin content or C / N ratio of the litter, the microclimate or the potential evapotranspiration of the sites (Meentemeyer 1978; Melillo et al. 1982; Vitousek et al. 1994; Johansson et al. 1995). Others papers link the litter biodegradation to groups of soil microorganisms (Cleveland et al. 2014). Few works link biodegradation time to humus systems (Zanella et al. 2018) and none to soil type.

We know that: a) there is a negative correlation between lignin content and tree wood formation (Novaes et al. 2010); b) in different tree species the lignin content varies from 15 to 40% (Sarkanen and Ludwig 1971); c) in each species the content varies by only a few units (26% +/- 2% in Picea abies (Raiskila 2008). Since Picea abies is the species that suffered the greatest damage, we think that the biodegradation times can reasonably be enclosed on the graph between the two lines of the Mull and Tangel-Mor, moving downwards in Mull more favorable conditions (high temperature and humidity) and upwards in opposite cases.

In 1966, McFee and Stone (1966) described a forest near New York where dead wood persisted in the soil long after being incorporated. After more than 100 years, the wood incorporated in the upper part of the soil was estimated at 15 or 30% of the initial volume. Even in the soil, these pockets of dead wood of more than 100 years show contents in N and P lower than the surrounding humus. Næsset (1999) states that the degree of contact with humus is one of the factors favoring the decomposition of wood. In particular, the author speaks of moisture rising from the ground ("Cross-section diameter, ground contact, soil moisture, and aspect were all found to have significant impacts on the decomposition rate constant. For different combinations of these characteristics the decomposition rate constant ranged from a minimum of 0.0165 per year to a maximum of 0.0488 per year"). This could mean that in a Mull (richer in organo-mineral aggregates and thus in water), the rise of moisture could be favored compared to a Moder.

However, a study by Bütler et al. (2007) assessed the relationship between the degree of decomposition of dead wood and the humus form

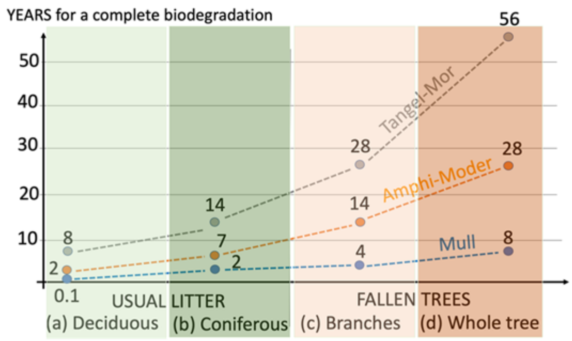

Figure 7 Estimation of the time necessary for a complete biodegradation of the fallen trees in three groups of humus systems (1- Mull; 2- Amphi-Moder; 3- Tangel-Mor). Mor and Tangel systems are very rare in the VAIA area and give an idea of what arrives in sites of slow biodegradation. We started with values (years necessary for a complete degradation; 0.1 means from few days to few months) published for litter: (a) good deciduous litter, (b) coniferous litter. As the time for lignin biodegradation is double compared to cellulose (Berg and McClaugherty 2014), we used a factor 2 from Coniferous litter (b) to Branches, material left in place after removing tree trunks (c) and to Whole tree (d). Consider that: i) lignin nearly doubles in % from leaves-needles to wood; ii) lignin is higher in coniferous than in deciduous material; iii) from Mull to Tangel or Mor, coniferous increases and deciduous decrease in the population of trees. We think we are not very far from the truth, but we are also aware that it is only an empirical estimate that requires control and feed-back. We do not see how we could act otherwise, today, in the face of the fait accompli.

but finds no link between the two. They take up the idea that only the rise of humidity counts.

With the study of Heilmann-Clausen (2001), a link between floristic wealth (which is probably associated with a soil richness gradient) and the diversity of wood decomposers, hence the rate of decomposition of wood. There is also talk of rising moisture, but also of pre-existing decomposers in the soil (Couture et al. 1983).

Culliney (2013) followed the decomposition of samples of wood included in different forms of humus and concluded the determining role of the macrofauna. This study shows that once integrated with humus, buried wood decomposes much faster in the mull than in the moder. This is one of the rare studies that goes in the direction of Figure 7 but unfortunately it lacks concrete elements to deduce a generalization to a forest context.

4.1 Soil, humipedon, humus system and humus form

To operate respecting the soil potentialities, we need to map the "biological soil" and to forecast its response to the event. The soil may be parted in three main layers: Humipedon, Copedon and Lithopedon (Zanella et al. 2018b, d). The top part is the more biological and the one that will first react to the event. To recognize the different forest humipedons (called "Humus systems", subdivided in "Humus forms"), we recommend the app TerrHum (free downloadable in the Education section of the App Store). Applied Soil Ecology published three Special Issues (Zanella and Ascher-Jenull 2018a, b, c) on humus forms. Ecologists, foresters and naturalists know that the living soil reacts differently according to the environment in which it develops. The fundamental traits of humus systems, and the main features that allow individuating the humipedons in the field are briefly resumed here down:

Mull system: absence of OH horizon

Moder system: Presence of zoOH horizon pHwater (A horizon) ≤ 5

Amphi system: presence of zoOH horizon, pH (A horizon) > 5; thickness of A ≥ ½ thickness of OH

Tangel system: presence of zoOH horizon, pH (A horizon) > 5; thickness of A < ½ thickness of OH

Mor system: nozOF or/and szoOH present; pH of A or AE or E < 4.5

4.2 Expeted reactions on each humus system

- On Mull system [digestive system of temperate environment and neutral substrate, developed at the top of Cutanic Luvisols - Typic or Inceptic Hapludalfs, or Haplic Cambisols - Typic Udorthepts, or Endogleyic Cambisols – Aquic Eutrudepts, or Luvic Phaeozems – Typic Argiudolls (IUSS Working Group WRB 2015; Soil Survey Staff 2015)] areas: let 1/2 of the material (steams, branches…) to the natural digested; estimated time of material digestion and transformation: 4-8 years (Figure 7). A large (7-40 cm) A organic-mineral horizon is expected to be generated and/or enriched in OC. A permanent or temporary switch to an Amphi system (formation of a zoogenic OH horizon) is possible under thick organic rests.

- On Moder system [digestive system of cold-temperate environment and acidic substrate, developed at the top of Dystric Cambisols – Spodic Dystrudents, or Entic Podzols – Humicryods *(IUSS Working Group WRB 2015; Soil Survey Staff 2015)*] areas: let 1/3 of the material (steams, branches…) to the natural digestion; estimated time of digestion: 14-28 years (Figure 7). We expect the formation of a thick Organic OH horizon (3-20 cm) and a thin organic-mineral A horizon (< 7 cm). A permanent or temporary switch to a Mor system is possible, with the formation of a thick organic layer in which a fungal biodegradation dominates; estimated time of digestion: 28-56 years or more.

- On Amphi system [digestive system of cold-temperate environment and limestone or dolomite substrate, developed at the top of Skeletic Luvisols – Inceptic Hapudalfs, or Epileptic Phaeozems – Lithic Hapludolls, or Rendzic Leptosols – Cryendolls *(IUSS Working Group WRB 2015; Soil Survey Staff 2015)*] areas: let 1/3 of the material (steams, branches…) to the natural digestion; estimated time of digestion: 14-28 years (Figure 7). We expect the formation of a thick Organic OH horizon (3-20 cm) and a thick organic-mineral A horizon (7-40 cm). A permanent or temporary switch to a Tangel system is possible, with the formation of a thick organic layer in which a zoogenic biodegradation dominates; estimated time of digestion: 28-56 years.

In conclusion, woody biomass generated by VAIA will mechanically increase the frequency of a very particular humus system, Legno, with all associated biological diversity. This "Para humus system" (Zanella et al. 2018c; Tatti et al. 2018) is usually "incorporated" punctually into another system. If the original system is a Mull, the biodegradation of wood may be faster than in a Moder (Figure 7). The literature shows that even a hidden Legno humus system, which is incorporated under the soil surface, lasts a very long time and could even be a means of sustainably storing woody carbon in the soil to cope with global warming (Moroni et al. 2010).

It would be very interesting to see what happens with the VAIA material and to compare real data with the forecasts calculated in Figure 7.

5 Long Term Actions (1-100 years)

To give a practical example, we decided to operate in a pragmatic way - a kind of classical method with greater importance assigned to the soil - on the three quarters of the area that suffered damage from Vaia, and to dedicate the remaining quarter to research.

5.1 Sylviculture on 75% of the VAIA surface. To support the forest regeneration.

The preconised measurements are adapted to the response of the biological soil. They can be reported in a few lines if together with the humus system we consider the naturalness of the damaged forest, the damaged surface in every type of forest and the quality of the natuiral renewal. These parameters are coded as follows:

A. Natural forests (reserves, parks…), not cut or very little, not for timber production

B. Forests submitted to natural forestry (no plantation, never clear-cut)

C. Forests subjected to more impacting cutting operations = wood production forests, band and spot cut

D. Forests from which fallen trunks have been removed and which have suffered damage to the soil and on the renewal due to the heavy means used for logging operations

AND

1. damaged by wind in spots or on less than 25% of coverage,

2. damaged on 25-50% of coverage and

3. damaged on 50% or larger surfaces;

AND

y. presence or potentially possible natural regeneration

n. absence or potentially difficult natural regeneration

Examples:

A1y: Natural forest (A), lowly damaged in spots (1) with potential or real natural regeneration (y);

B2n: Forests submitted to natural forestry (B), damaged on 25-50% of coverage (2) and absence or potentially difficult natural regeneration (n).

The silvicultural measures that we recommend on the 75% of the surface that has suffered damage from VAIA are the following:

In A, it is not necessary to detect the humus system:

- A1: do nothing
- A2: remove only the stems easy to take out of the forest without damaging the soil (along the roads);
- A3: remove of the stems easy to take out of the forest without damaging the soil (along the roads and using a light and low-impact cableway);

In B:

- B1y and B2y: where possible with light soil damages, remove only the good-for-sawmill stems;
- B1n, B2n and B3y: do nothing;
- B3n: where possible with light soil damages, remove ½ or 2/3 of the steams in case of Mull or (Moder and Amphi) respectively;

In C:

As in B; in addition, where possible, fragment half the branches let on the soil.

In D:

Fragment half the branches and let the sites to natural evolution. In case of erosion danger, plants with native species in harmony with the surrounding natural forest.

The potential soil types and forms of humus in the areas that underwent the Vaia event are shown on Table 1.

At this point of the analysis, with knowledge of causes and effects, the politician makes decisions for the future of the environment in which his community lives.

5.2 Research on 25% of the damaged area

5.2.1 Possible research on soil erosion, N cycle, biology and biodiversity

In slope erosion issues, Battany and Grismer (2000) and Stanko et al. (2011) in an experiment on soil erosion of vineyards, showed that below 16% slope, if erosive processes exist they are minors compared to steeper slopes. Holvoet and Muys (2004), Linser et al. (2018) and Rogers and Schumm (1991) specified that runoff in a forest context becomes intense from 20% slope if there is no ground cover. Runoff is slowed down as soon as 8 to 10% of the area remains afforested by bands parallel to the contours. A more recent synthesis (Gobin et al. 2004; Guerra et al. 2017) mentions that any landscape with a slope > 3-5% is subjected to soil erosion.

In detail, there are questions on the flow of nitrogen especially in the form of nitrates that enrich streams but impoverish forest soils. Törmänen et al. (2018) recently experienced the effect of the contribution of 40 kg/m² of exploitation residues on the N cycle in soil superficial horizons (0 and 0-5cm). They tested it for 3 species, *Betula pendula*, *Picea abies and Pinus sylvestris*. All species combined, 18 months after the intake, between 150 and 200mg/kg o.m. nitrate was produced. There was no nitrification in the control (now input of residues) for which the mineral N production was limited to ammonium. However, in a simple clear-cut without the addition of milling material, Smolander and Heiskanen (2007), Smolander et al. (2008) and Finér et al. (2016), by comparing a clear-cut spruce stand with an existing stand, showed that the net N mineralization rate was low without producing NO_3^- in the stand in place while mineralization and nitrification rates were very high in the cut area. Net nitrification was 29 times higher in the clearcut, in line with Likens' work.

Then there are all the effects on soil biology, we export everything, we do not export everything, it's always the same question. The "cleaning" of the cut area with the export of slash is unfavorable to biodiversity. Indeed according to Landmann et al. (2009, 2014, 2015), wood debris are home to many living species, different from those of large dead wood. They are home to a large part of saproxylic insect and ascomycete communities. They provide shelter for amphibians, reptiles, small mammals, promote colonization by mycorrhizae, and maintain microclimatic conditions favorable to mosses. The few studies available in temperate forests show that compared to a conventional harvest leaving slash on the ground, the export of small wood remains decreases in the short term the diversity of saproxylic insect communities at plot scale, by modifying their composition (Canadian Institute of Forestry 2019).

5.2.2 Possible research on N and C cycles, erosion, leaching, evapotranspiration, nitrate concentration in forest soil solutions after windthrow

Increased levels of nitrate concentration in the soil solution could be expected after forest damages following strong wind events. An increase in nitrate leaching into the deeper soil horizons was observed in previous studies on forests affected by storms (Legout et al. 2009; Hellsten et al. 2015) as well as by clear-cut harvests (Gundersen et al. 2006; Kreutzweiser et al. 2008). Diminished nitrogen uptake by plants and/or increased mineralization rates could be the driving process that explain nitrogen losses by leaching after forest disturbance (Vitousek et al. 1979; Ranger et al. 2007). Changes in the soil climate of forest gaps due to decreased transpiration and increased sun exposure (Kreutzweiser et al. 2008) favor organic matter decomposition and nitrate formation after nitrification. Nitrate concentration in soil water has been found to reach a maximum a few years after the storm, up to 15 years depending on the study case. Indeed, the impact of windthrow on nitrate leaching is modulated by important factors such as the level of nitrogen deposition (Akselsson et al. 2004), the extent of ground vegetation cover (Legout et al. 2009; Hellsten et al. 2015) and the magnitude of the area affected by windthrow.

Nitrate leaching below the rooting zone may potentially contaminate groundwater, cause eutrophication of surface water (Kreutzweiser et al. 2008) and contribute to soil acidification. This could further worsen the already critical situation of the VAIA forest ecosystems. European forests have been exposed to acidifying anthropogenic deposits for several decades and the Alps are still receiving high loads of atmospheric reactive nitrogen due to the proximity of emission sources in the Po Valley (Rogora et al. 2016). High inorganic nitrogen concentrations in soil solutions were found in sites with high N deposition loads (Andreetta et al. 2019), where a regular N flux out of the rooting zone can represent a risk of ground- and freshwater pollution. Increased nutrient availability could also affect tree carbon partition patterns, with a shift of carbon allocation from roots to aboveground woody biomass (Janssens and Luyssaert 2009). This nitrogen-induced carbon allocation pattern could ultimately increase the sensitivity of trees to extreme windstorms, likely leading to an alarming positive feedback loop.

5.2.3 Studies on soil microbial communities

Before considering the whole forest soil as a digestive system or to subdivide the soil in parcels with different "managements", as an agricultural chemist I would recommend observing in the lab the degradation of the fragmented wood by endogenous microorganisms. It could be possible to identify and isolate at least the dominant ones and let them grow under controlled conditions using wood as a substrate. Soil respiration (IRGA), changes in wood composition (LC-MS) and composition of microbial communities (DGGE, 16S/18S-RNA fingerprinting) could be studied. This could be a preliminary basis before infield studies, in order to get an idea about the best strategy to be applied in the whole forest.

Soil microbial communities can play several important ecological and physiological functions in a forest (soil organic matter decomposition and control of its cycle; regulation of mineral nutrient availability for plants; atmospheric nitrogen fixation; formation of mycorrhizae; production of biologically active substances able to stimulate plant growth; etc.), ameliorating soil physical and chemical conditions, and consequently soil habitability for plants, as observed in many soil-plant systems (Sofo et al. 2010, 2012, 2014). There is a growing interest in the maintenance of forest functionality and its connected ecosystem services. It seems that the soil microbiota, particularly its biodiversity, allows forest systems to better overcome natural and anthropic perturbations by improving their recovering capacity (resilience concept). Thus, a survey on soil microbiological data of the forests of North-East Italian Alps, that were strongly damaged by wind on 30 October 2018, is urgent for planning the best strategies for their management in the next future. Particularly, attention should be given to changes in the structure, dynamics and complexity of soil microbial communities, in order to evaluate soil health status before and after planned interventions.

One of the easiest and reliable techniques for defining soil microbiological status is the determination of microbial metabolic/functional diversity by the spectrophotometric Biolog® method, that has a high discriminating power between microbial soil communities from different soil environments. Culture-based and genetic techniques have been used successfully in forests to ascertain the presence of some types of microorganisms. This is particularly important in damaged forests, where soil microorganisms, and particularly fungi, can play an important role for fast forest recovery, as both bacteria and fungi respond to forest perturbation already in the short term. Besides microbiological and genetic analyses, nowadays next-generation sequencing (NGS), coupled with bioinformatic tools and metagenomic approach, made it easier to comprehensively analyze microbial communities in any type of matrix, including soils.

On this basis, short-time effects on microbial functional and genetic diversity of different management systems after the 30th October disaster could be evaluated by a combination of culture-dependent and culture-independent methods, accompanied by microscopy. This is urgent for better understanding the degree of forest resilience in our case study.

5.2.4 Soil studies as a basis for forest renewal

A simple comparison between i) the soils prived of trees due to Vaia, ii) the soils now recovered with different species and processes by the silviculturist, and iii) the other nearby soils that instead continue to support the forest that survived Vaia.

We could make pedofauna inventories twice a year, with associated chemical-physical and biological (example: DNA) analyzes, for n years (the longer, the better). We could classify the forms of humus (with the app TerrHum), we could estimate the natural renewal (counting the seedlings in sample areas), we could collect soil samples, we could extract the animals and make chemical-physical and biological measurements. Then we will compare the data statistically, choosing the factors we want, such as the type of silviculture, the quality of the renewal, the altitude or the type of forest, but also the type of feeding of the soil (nothing, leaves, chips, branches, trunks ...).

6 Additional Economical Consideration

From an economic point of view, VAIA had an interesting dynamic effect on the timber price. After VAIA, the prices of timber had literally dropped (Ebner 2018; Talignani 2019), with the consequent disadvantage of using most of the fallen timber. As a consequence, according to scientists, there were problems related to the spread of insects and fungi harmful even to the living woods that remained standing. However, in a second time the fall in the price of timber attracted unexpectedly forest companies and foreign

European and Chinese buyers, arising the timber price which doubled. Market could be very efficient to use resources.

Figure 8 shows the dynamic of the standing timber price and the logs price in the Trento province.

The collapse of the prices hit in particular the standing timber that fell from 67,6 €/m^3 to 29,36 €/m^3 (-56.6%) from October to November 2018, while the price decline of logs has been more limited (-16%).

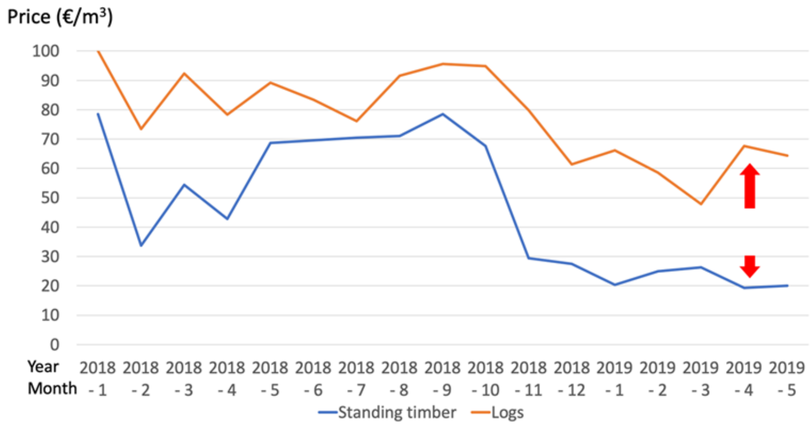

Figure 8 Dynamic of the monthly timber prices (€/m3) in the period January 2018 – May 2019. Source Commerce chamber of Trento (IT), www.legnotrentino.it/asteonline

In the first months of 2019 there has been a recovery in the price of logs (64 – 67 €/m^3) due to the effect of foreign buyers, while the price of standing timber remains at very low levels (19 – 20 €/m^3).

Currently, the companies are removing all the woody material, without releasing wood on the ground, as if VAIA was an unexpected sylvicultural cut operated a large forest area (as it currently arrives in Canadian, Swedish, Russian woodlands). If we want to let part of the material on the ground for stimulating the soil functionality, it is necessary to intervene rapidly raising artificially the timber price (imposing a minimum price) or establishing artificial constraints in the contract specifications (defined quantities of material to release in the forest), to guarantee the renewal of the woods in the long term.

Another exciting aspect ponders the dynamics of the free market. The storage of timber has a cost that risks not being compensated for by an expected price increase that remains unpredictable in a globalized market. It is sufficient that another catastrophic event arrives elsewhere to defeat the price forecasts. It is, therefore, more prudent to store only the wood that can be used for local activities and to rely on a global market for the rest. With growing domestic demand and booming export industry, China is both a major importer and exporter of wood products. Coupled with an environmental policy to protect the country's remaining natural forests and economic policy, China has not only increased its import of timber products but has tended to import less processed materials.

In 2018, China's logwood imports had increased by 8% compared to the previous year, rising to an overall of 60 million m^3, of which about 42 million m^3 (+ 9%) were softwood and 19 million m^3 (+ 8%) were hardwood logs (Jauk 2019). Zhu (2019) shows (Appendix 2) that imported softwood logs quantity and price of China in 2018, 42% of softwood logs shipments arrived from New Zealand and 19% from Russia, followed by the US (12%), Australia (10%), Canada (6%) and Uruguay (5%), and the average price is about 139 \$/m^3 (around 125 €/m^3).

The 8 million m^3 of VAIA's timber correspond to a volume of softwood within reach of Chinese buyers, and the price fluctuations of Trento timber (Figure 8: months 2019-3, 2019-4) could be related to their preferences. To avoid empty export containers back to China, trading companies arrived in Europe would choose to transport logs back to China. Such logs are most likely used to produce medium grade furnishings sold in the country. Therefore, Chinese buyers were likely to buy logs and not standing timber whose prices remain low (Figure 8). The fact that the cost of wood rose to avoid returning to China with empty containers (and not for reasons of competition with European companies) left everyone stunned. The unforeseeable is... not predictable (which corresponds to a first direct feedback of this review). In this case, for example, timber extraction has become economically advantageous even in less accessible parts of the forest, with an additional consequent ecological impact to be taken into account. All this could be an example of unforeseeable behavior to have in mind if it were decided in the future to face global warming seriously.

7 Conclusions and Response to Governor of Veneto Region

Dear Governor of Veneto Region,

Thanks for asking for scientific advice.

Scientists have many solutions that depend on their character, training, intelligence, connection with the territory. Unfortunately, there is a difference of opinion on the question of how to intervene after Vaia. It is not usual to publish contrasts in scientific articles. There was a general agreement on the need to follow a "precautionary principle", to think that the territory you govern should be transmitted with its functional biodiversity to future generations. On how to do this, unfortunately, is where the shoe still pinches. Below you will find the summary of the advice of the authors of this article, and some surprises.

7.1 Is it better to let nature treat its wound?

Yes, it would be better. Where possible, it is better to leave it to nature. The whole discussion can be foound at https://hal.archives-ouvertes.fr/hal-02342793.

There is an article in The Guardian on 15 Oct. 2017: From dead woods to triumph of nature, 30 years after the Great Storm. The devastating winds of 1987 felled 15 million trees but also prompted a radical change to the way we work with the countryside to let it heal itself.

“Scords Wood was left alone,” says Tom Hill, the National Trust’s trees and woodlands specialist. “There’s been no intervention at all, and it’s now a thriving woodland in terms of its diversity.”

“Veteran trees have decay and growth happening at the same time. One of the biggest attitudes that changed was the process of decay being seen as an integrated part of life not just something dirty or rotten.”

“Storms mix things up, they allow light to get in, which is a vital factor. Toys Hill is like a mosaic of different habitats and light and shade, and it has a very diverse structure. That’s exactly what you want if you’re seeking to maintain healthy woodland. Destruction is very important, and nature is self-destructive and self-healing at the same time.”

Link: https://www.theguardian.com/environment/2017/oct/15/british-woodlands-30-years-after-great-storm

7.2 Actions

Examples of short term actions (1-5 years), concerning security, vulnerability/sensitivity analysis and maps, are reported in section 3 . In section 5.1, you dispose of a list of long term actions (1-100 years) that allow renewing the forest on 75% of the damaged surface; in 5.2, you find a list of research projects to place on the remaining 25% of the damaged surface for collecting the necessary feedback and improve the forest restoration action.

8 Artistic Interpretation and Call for Earth’s Climate Protection

Science alone is not enough. The future must also be invented (not only understood). Science and art are two sides of a single vision. Until the 17th century, art referred to any skill or mastery and was not differentiated from crafts or sciences. Because to understand things, one must first imagine them as individual mental creations. This is the reason why each individual understands things in her/his own way. Truth reveals itself in the future, it cannot be known in the present time, only "imagined". It generates itself as an amazing and ever-changing historical collective construction.

8.1 “Listen to the soil”, of Bonneval Karine (FR)

Can we listen to the ground, what sounds could the soil make?

Soil is not a simple and inert material, it is a world in itself, complex and living. The soil is full of many symbols: it is our planet of course, the soil in which we grow our food, a material first, the surface on which we are anchored, the territory on which we live. We walk on a complete universe that it seems important today to give to hear in order to understand the world below us in a different way.

It is the product of decomposing living beings and shelters an immense diversity of animals, plants, fungi, bacteria...

The life of these organisms can be heard (Figure 9): their activity generates sounds. In the ceramic sculptures are played different recordings of different soil biotopes, in order to offer to the audience a sound landscape of the soil.

A soil in good shape is noisy.

8.2 "L'urlo di Vaia", with the permission of the authors Vera Bonaventura (IT) and Roberto Mainardi (IT)

Inside Malga Costa (alpine hut for cows), it will be possible to relive, condensed in 5 minutes, what the populations and trees of Trentino have lived in 5 hours between 28 and 29 October 2018. "We probed the various forms of art we could use ... and we found ourselves with only a sound in our hands ... which, from interviews with people who lived Vaia, was an element tragically imprinted in our memory". A glimpse of this sound, from youtube: https://www.youtube.com/watch?v=SFGWU7gjQ48

8.3 A cell-phone referendum

Even after Covid-19, the climatic situation of our planet leaves no hope for a long period of peaceful coexistence, unless a decision is made to act as a whole humanity. We suggest to put the average air temperature of planet Earth (mean surface air temperature = 15 ± 2 °C) among the humanity's assets (UNESCO Wolrld Heritage List). As if the air temperature was part of our common home, related to our activities, and in need of peculiar protection.

We suggest to organize a first worldwide cell-phone referendum (Figure 10), a first conscious and democratically determined step in the Anthropocene. During the coming Olympic Games in Tokyo (July 2021). Would you help us and sign a petition addressed to the Organising Committee of the Tokyo 2020 Olympic Games?

https://secure.avaaz.org/community_petitions/en/to_the_organsing_committee_of_the_tokyo_2020_olymp_lets_organise_a_worldwide_referendum_and_stop_the_climate_from_warming/.

Figure 9 Left: Listen to the soil, sometimes I hear the plants whisper, Botanical museum Berlin, 2018. An art and science project, in collaboration with Fanny Rybak, bioacoustician in Neuropsi, Paris -Saclay/Rillig Lab, directed by Matthias Rillig, laboratory of plant ecology, freïe Universität, Berlin/Johannes Lehmann, director of the soil and crop sciences section at Cornell University .A project supported by the Diagonale Paris - Saclay, the Drac Centre-Val de Loire, Micro Onde Centre d'Art, Cornell University.

Figure 10 This figure illustrates the evolution of biodiversity on our planet, from: (Zanella 2018). Life develops between the molecular world of the organic substance in the soil and far away to the nearest galaxy clusters. The orange background corresponds to the threat of average rising air temperature. In the middle, two figures with an opposite meaning, the gray spectrum of the first atomic bomb and the "Pioneer plaque" launched in 1972 by NASA in the space to indicate our position in the universe to other extraterrestrial living beings.

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